Imaging Challenges Theory of High-temperature Superconductivity

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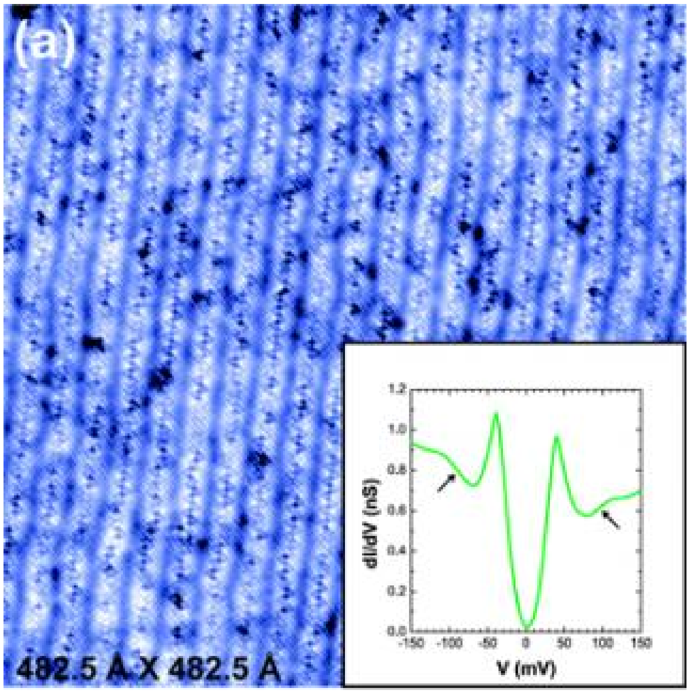

Scanning tunneling microscope "topographic map" of a sample of cuprate semiconductor shows the locations of atoms in the crystal lattice. The inset shows how the current flow at a single point of the scan varies with voltage, with "kinks" (arrows) that indicate the presence of lattice vibrations and electron pairs. Credit: Davis Lab/Cornell University

By observing events at the scale of single atoms, Cornell researchers have found evidence that the mechanism in high-temperature superconductors may be much more like that in low-temperature superconductors than was previously thought.

"This came as a huge shock," said J.C. Seamus Davis, Cornell professor of physics, who with colleagues reports the findings in the Aug. 3 issue of the journal *Nature*.

Superconductors are materials that conduct electricity with virtually no resistance. The new research may shed light on how superconductivity works in modified copper oxides known as cuprates, which superconduct at the relatively "high" temperature of liquid nitrogen.

"The main expectation has been that electron pairing in cuprates is due to magnetic interactions. The objective of our experiment was to find the magnetic glue," Davis said.

Instead, the researchers found that the distribution of paired electrons in a common high-temperature superconductor was "disorderly," but that the distribution of phonons -- vibrating atoms in the crystal lattice -- was disorderly in just the same way. The theory of low-temperature superconductivity says that electrons interacting with phonons join into pairs that are able to travel through the conductor without being scattered by atoms. These results suggest that a similar mechanism may be at least partly responsible for high-temperature superconductivity.

"We have shown that you can't ignore the electron-phonon interaction," Davis said. "We can't prove that it's involved in the pairing, but we have proven that you can't ignore it."

The superconducting phenomenon was first discovered in metals cooled to the temperature of liquid helium, about 4 Kelvin (4 degrees above absolute zero, -270 degrees Celsius or -452 degrees Fahrenheit). Cuprates can become superconductors up to about 150 Kelvin (-123 degrees Celsius or -253 degrees Fahrenheit). They are widely used in industry because they can be cooled with liquid nitrogen (boiling point 77K), which is less expensive than liquid helium.

Drawing on a technique developed at Cornell a decade ago to measure the vibrations of a single atom, Davis extended the measurements across an entire sample, using an improved scanning tunneling microscope (STM). The STM uses a probe so small that its tip is a single atom; positioned a few nanometers above the surface of a sample and moved in increments smaller than the diameter of an atom, it can scan a surface while current flowing between the tip and the surface is measured.

For the experiments reported in Nature, the researchers examined bismuth strontium calcium copper oxide, a cuprate that superconducts below 88 Kelvin. At each position in their scan they conducted several measurements, including one to detect the presence of paired electrons and one to show the presence of vibrations in the crystal lattice. Each of these appears as a "kink" in current flow as voltage is increased.

"We simultaneously see lattice vibrations with which clouds of electrons are associated," Davis said.

The researchers found the same to be true with a variety of different "dopings," in which atoms of other elements are inserted into the crystal to create "holes" where electrons are missing. Since the holes change the magnetic fields in the crystal, this suggests that magnetic effects are not an explanation for the electron pairing, they said. On the other hand, making the cuprate sample with a different isotope of oxygen -- one with an atomic weight of 18 instead of 16 -- changed the magnitude of the results, reinforcing the idea that the pairing relates to vibrations of the atoms.

"A direct atomic scale influence of [lattice vibration energy] on [electron pairing energy] is implied," the researchers conclude in their paper.

Source: Cornell University

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